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A High-precision Control System of DC Motor Based On DSP

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Abstract

A new scheme of high-precision DC motor control system based on DSP-TMS320F28335 as a core control chip is proposed in this paper. The scheme adopts PID control and Active Control strategy. The tests result greatly meets the needs of rotating and reversing performance in the reversible control system. The scheme, using a simple structure, is feasible and reliable, which shows a great engineering value in the field of high-precision control.

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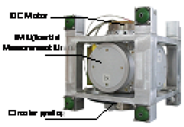
Keyword: PID; DSP; Active Control

1. Introduction

Rotation-modulating INS (Inertial Navigation System) is an effective method to alleviate the conflict between the precision and cost of the system [1]. Through rotating the system changes the constant drift in the sensitive axis coordinate system of the gyroscope and accelerometer into a variation of zero-mean in the navigation coordinate system, which greatly improves the navigation precision. In the system, the control precision of motor directly affects that of navigation. Figure 1(a) shows the rotator of the system, with a grating angle measuring system at the bottom, it can output the angle feedback signals through clockwise (CW) and counter clockwise (CCW) rotations of inertial devices driven by the DC motor.



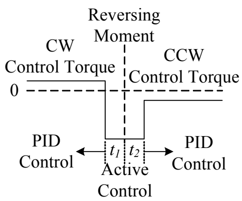


Fig. 1.(a) Rotator; (b) Schematic diagram of the Active Control

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2. Control algorithm

2.1. Control strategy

PID control [2], with a simple structure and robustness to some extent, is proved one of the most commonly used control methods. Using only PID, it's still very difficult to satisfy the requirement that the angular position error as the motor reverses is less than 40″ . Meanwhile the algorithms of other methods are generally so complex that hard to be directly applied to reduce the angle error as reversing. Considering engineering needs, a simple and effective scheme is proposed, which, using active control, removes the PID control and reverses the motor swiftly by applying a higher voltage at a short time.

2.2. Control loop

Rotator model is shown in Figure 2. Torque motor can be equivalent as proportional component, wherein C_m is the torque coefficient, R_a is the armature resistance, generally provided by the manufacturers; $\tau = J / B$, $K_\omega = 1/\mathrm{B}$,wherein J is the moment of inertia of the rotator, B is the viscous friction coefficient; M is the output torque of the motor, M_f is the static friction torque; U_{in} is the input voltage, ω_o is the output angular velocity. These parameters estimated by the open-loop test method are shown in Table 1.

Table 1. Estimate of parameter

Parameters	B	J	M_f	τ
Estimate	0.11	$0.075 kg \cdot m^2$	$0.06 N \cdot m$	0.68

Based on rotator model, the control loop (Fig 2), which uses the grating angle measuring system as feedback, is completed by adding the PID controller. Wherein θ_a is the actual angle, θ_l is the ideal angle , also a command angle, pre-set by the control computer; ω is the actual angular velocity; U_{PID} is the control voltage generated by the PID, U_F is the reversing voltage , U is the total output voltage. K_p, K_i, K_d are the proportional, integral and differential parameters of the PID controller respectively. We can see the circular grating as a proportional component whose proportional coefficient K = 1.

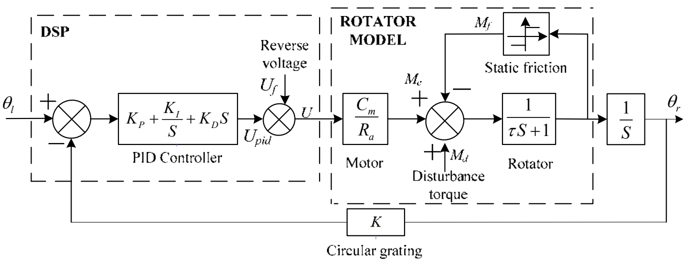

Fig. 2. System control loop

2.3. PID parameters tuning

There are a couple of ways of tuning PID parameters; a widely used method in engineering called Ziegler-Nichols (Z-N) tuning is adopted in this paper. The Z-N tuning is that in the case of a closed loop, the integrator and derivative gains are reduced to 0, using only proportional feedback control. And then a disturbance is added to the system and K_p is increased from 0 to some critical value $K_p = K_u$ at which sustained oscillations occur. Then the proportional gain is called the critical gain, denoted by K_u, and the corresponding period of sustained oscillation, T_u.The Z-N tuning, using K_u and T_u obtained by SIMULINK, calculates the parameters of the controller by the empirical formula. The formula and final values of parameters tuning are showed in Table 2.

Table 2 Values of PID parameters

Parameters	K_p	K_i	K_d
Tuning formula	$0.6 K_u$	$0.5 T_u$	$0.125 T_u$
Tuning value	1380	27600	16

2.4. Active Control

The system, requiring rapidness, smoothness and no overshoot, asks for a quite strict performance of reversing. Considering CW and CCW rotation, with the predicted reversing moment, a combination of the active control and PID control are taken to achieve to reverse rapidly and smooth, showed in Figure 1(b). Active control is a new control method, which means applying a higher reversing voltage at the moments before the reversing command arrives in order to drive the rotator to reverse and accelerate to the angular velocity in a very short time.

Assuming the steady rotation speed of the motor is ω_c, the ideal angular velocity is:

$$\theta_a(t) = \begin{cases} \omega_c & (0 < t \le T) \\ -\omega_c & (T < t \le 2T) \end{cases} \tag{1}$$

Wherein, T is the period of the rotation. So we can calculate the voltage at the period changing from CW to CCW of the rotator, as showed in Equation (2).

$$U_F = \begin{cases} 0 & (0 < t \le T - t_1) \\ -U_{\max} & (T - t_1 < t \le T + t_2) \\ 0 & (T + t_2 < t \le 2T - t_1) \end{cases} \tag{2}$$

Wherein, $U_{\max}$ is the reversing voltage, and the duration of it is: $\Delta T = t_1 + t_2$. Fig.2 shows the relationship between the output torque and the voltage.

$$U_{\max} = \frac{MR_a}{C_m} \tag{3}$$

According to the principles of rigid body rotation dynamics, we obtain:

$$M \Delta T = 2\omega_c J \tag{4}$$

From the equations above, we derive $U_{\max}$:

$$U_{\max} = \frac{2\omega_c J R_a}{\Delta T C_m} \tag{5}$$

The approximation of $U_{\max}$ can be calculated by the above equation. But taking the friction into account, the value used in practice is generally a slightly bigger than in theory. The key of adjusting $U_{\max}$ is to ensure that the angular velocity of the motor could be as close as ω_c while removing the reversing voltage. When recovering the PID control, the initial value should be assigned to the integrator because of its memory function. Considering the invalidity of proportional and differential roles while rotating smooth, the friction torque is largely offset by the output of the integrator. The initial value of the integrator could be got from the following:

$$\frac{M_f + B\omega_c}{K_m} \tag{6}$$

3. Control circuit design

In order to meet the precision and high frequency control requirements, DSP-TMS320F28335 produced by *Texas Instruments*, which is a high-performance digital signal processor designed for the control area is used as a core control chip [4]. LMD18200, which is a DMOS full-bridge power amplifier produced by *National Semiconductor,* is taken as the power amplifier.

The digital signal, which is a Quadrature Encoder Pulse (QEP) and output directly by the grating angle measuring system, could be connected to the QEP module of DSP after conversion to CMOS level. Then the QEP module automatically counts according to the direction of rotation. The control voltage calculated by DSP, converting into a PWM signal, is connected to LMD18200.The complete circuit schematic diagram is shown in Figure 3(a) and the corresponding PCB is shown in Figure 3(b).

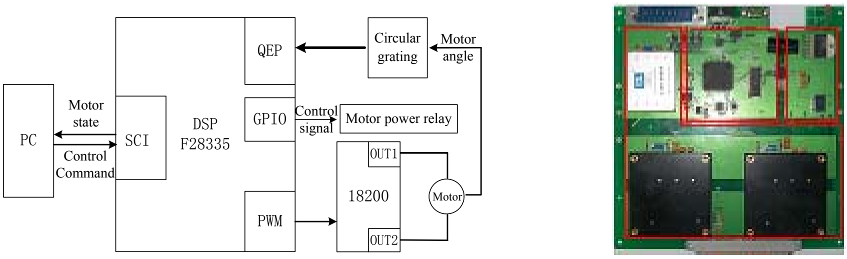

Fig. 3. (a) Circuit diagram of the system;(b)Motor Control PCB

4. Test Results

The rotator should be fixed horizontally and statically; then the controlling program will be launched to control the rotation; meanwhile, launch the sampling program, whose sampling rate is 1000Hz, to collect the angles. Tests were conducted 5 times.

Table3 Uniform rotation tests results

Tests	Angular velocity(° /s)	Precision(ΔΩ/Ω)	Stability (″)
1	10.0000034	-3.4e-007	4.27
2	10.0000021	-2.1e-007	3.78
3	9.9999964	3.6e-007	4.35
4	9.9999955	4.5e-007	2.73
5	9.9999954	4.6e-007	3.54
Average	9.9999985	1.44e-007	3.73
Standard deviation	1.53e-006		

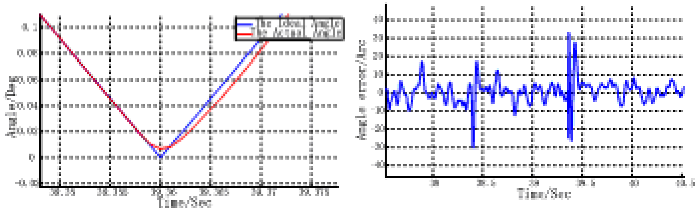

Fig. 4. (a) Angle of reversing process;(b) Angle error of reversing process

Table 4 Results of reversing test

Tests	1	2	3	4	5	Average
Maximum angle error (")	34	37	39	33	35	36
Reversing time	2	2	3	2	2	2

Linear model $\phi(t) = \Omega t + \phi_0$ is used to fit the actual cycle angle created by the rotator, the rotation stability is presented by the mean-square deviation of fit residuum; the angular velocity precision is presented by the difference between fit and ideal angular velocity. The angle error is presented by the difference between the actual angle and the ideal angle. The tests results are as follows: the five test result is shown in Table 3, the angle and angle error in a certain reversing process is respectively shown in Figure 4(a) and (b). Table 4 illustrates the reversing control performance of 5 tests.

Tests results show the rotation stability precedes 5", the angular precision is better than 0.000001, switching time and overshooting are less than 3ms and 40 " respectively.

5. Conclusion

Active Control is an effective and simple solution to reduce the angular position error as the motor reverses.

The scheme, with a simple structure and a high control precision, is proved feasible and reliable to meet the needs of the Rotation-modulating INS, which shows a great engineering value.

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